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**“The chemical composition of gahnite and garnet as
exploration guides to and indicators of rare element (Li) granitic pegmatites”**

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INTRODUCTION

Rare earth elements (REE), Li, U, P, Be, Cs, Sn, Ta, and Nb are found in granitic pegmatites and constitute a group of economically important and strategic commodities known as rare or scarce metals (from here on this is referred to as rare element pegmatite and rare metal mineralization). The United States lags behind other countries in the production and reserves of rare metals such as Li (USGS report 2009), an economically and strategically important element used in a large number of applications, but most importantly for making rechargeable Li-batteries for hybrid and electric vehicles, the telecommunication industry, rocketry (propellants), and nuclear applications (nuclear weapons and reactors). However, most of the currently known reserves for Li come from private companies or foreign countries.

Lithium can be mined from brines and granitic pegmatites (Kesler et al., 2012). Černý and Ercit (2005) classified granitic pegmatites based on geological, paragenetic, and geochemical characteristics into five classes and subdivided them into subclasses, types, and subtypes. With the exception of pegmatites of the muscovite class and from two subclasses, the pegmatites from the remaining subclasses are important hosts of Li, REE, or REE-Li mineralization. Those two subclasses host uranium or beryllium mineralization. Černý and Ercit (2005) emphasized the need for further studies, in particular the need for case-studies and geochemical and petrogenetic investigations.

Although bulk-rock chemical analysis is a good method to distinguish between barren and fertile granite and pegmatites (e.g., Selway et al., 2005), it has also been shown (Kleck and Foord, 1999) that the bulk-rock chemistry of pegmatites provides little information about fractionation and genetic processes, because in some cases they contain low amounts of the incompatible trace elements that characterize differentiated pegmatites. Instead of bulk-rock chemistry, the chemistry of pegmatite minerals is more useful in understanding fractionation processes (e.g., Kleck and Foord, 1999). Gahnite (ZnAl_2O_4), the Zn end-member of the spinel group of minerals ($[\text{Zn,Fe,Mg}]\text{Al}_2\text{O}_4$), and garnet (Mn-Fe-rich) are common accessory minerals in both rare element-rich and barren granitic pegmatites and evolved granites. These minerals have been studied extensively in metamorphosed massive sulfide deposits and their major and trace element chemical composition has been used successfully as exploration guides for ores of this type (e.g., Spry and Scott, 1986a,b; Morris et al., 1997; Heimann et al., 2005; Spry et al., 2007; Spry and Teale, 2009; Heimann et al., 2009; 2011). Because of their common presence as accessory minerals in evolved granitic pegmatites (e.g., Novak et al., 2003), these minerals hold the potential for being used to discriminate economic pegmatites from those devoid of rare metal mineralization. However, their major and trace element chemical composition in rare element granitic pegmatites has only been investigated in detail in a few pegmatites. Because of their resistate character, gahnite and garnet can be used in exploration programs that target concealed or undiscovered mineral deposits (e.g., sedimentary or glacial cover, sands, mineralization haloes). In addition, garnet and in less degree gahnite are widely distributed and crystallize throughout a pegmatite system, which make them useful indicators of magma evolution. Understanding the chemistry of these minerals and its relationship to rare metal mineralization in granitic pegmatites is therefore necessary for developing new genetic and exploration models.

Morris et al. (1997) pointed out the exploration potential of gahnite compositions for rare metal mineralization in pegmatites based on its major element composition. In addition to being found in rare element-rich and -poor granitic pegmatite and granite (e.g., Tulloch, 1981), gahnite and zincian spinel also form in metamorphic rocks spatially associated with Zn-Pb massive sulfide deposits, non-sulfide Zn-deposits, Al-rich granulites, iron formation, skarn, marble, and

metabauxite (e.g., Spry and Scott, 1986a,b; Feenstra et al., 2003; Heimann et al., 2005; Spry and Teale, 2009). A couple of studies suggest that the most common trace elements found in gahnite in pegmatites are Li, Co, Cr, V, Rb, Ba, Ga, Cu, Ti, and Sn (e.g., von Knorring and Dearnley, 1960; Soares et al., 2007). However, detailed studies on the major and trace element chemical composition of gahnite in evolved granitic rocks and pegmatites are scarce (e.g., Szuszkiewicz and Lobos, 2004), and our knowledge on how to discriminate between gahnite chemistries in different rock types is limited. For example, previous comparative studies (Batchelor and Kinnaid, 1984; Morris et al., 1997; Heimann et al., 2005) indicate that the major element chemical composition of zincian spinel in granitic pegmatites, metabauxites, and metamorphosed massive sulfide deposits overlap in terms of their Zn-Fe-Mg ratios and all have very low Mg contents. Furthermore, we are not aware of any study that has published the trace element composition of zincian spinel obtained *in situ* by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS), except for a recent abstract on gahnite from metamorphosed massive sulfide deposits (O'Brien et al., 2011). Therefore, to use gahnite as a resistor indicator mineral in the search for rare metal mineralization in pegmatites, as proposed by Morris et al. (1997), major and trace element compositional differences of gahnite in different kinds of pegmatites and metamorphosed massive sulfide deposits need to be determined.

Gahnite has also been proven useful in understanding magmatic differentiation processes in rare element pegmatite fields in Brazil (e.g., Soares, 2004; Soares et al., 2007). Although it is known that in a fractionation process Zn tends to concentrate late in iron minerals, which should result in higher Zn/Fe ratios with differentiation (e.g., Batchelor and Kinnaid, 1984; Morris et al., 1997) and may favor gahnite crystallization, the significance between the presence of gahnite in pegmatites (e.g., Soares et al., 2007) and its relation to the presence of rare metal mineralization has not been systematically studied.

Garnet is also a common accessory mineral in granitic pegmatites, including complex Li-rich pegmatites and evolved granites, in addition to being a common phase in metamorphic rocks of various grades. Previous studies have focused on the Fe/Mn ratios of spessartine garnet in granitic pegmatites. In particular, it has been shown that spessartine garnet is common in quartz-rich pegmatites that contain Li-rich minerals, and that its Fe/Mn ratio varies depending on the type of pegmatite, the presence of rare metal mineralization, and (or) the location within the pegmatite (e.g., Baldwin and von Knorring, 1983). For example the Fe and Mn content of garnet is different in Li-mineralized pegmatites compared to pegmatites low in Li (Baldwin and von Knorring, 1983), and in different pegmatites in the same field that are rich in various rare elements (e.g., Novak et al., 2003). However, the detailed compositional variation of this mineral in other types of granitic pegmatites is still highly unknown.

The number of published major element compositions of gahnite and garnet from rare element granitic pegmatites and barren pegmatites in the United States and elsewhere in the world is very limited (< 200), which is surprising given the economic importance of this type of mineralization and the large number of rare element pegmatite fields in the U.S. and around the world that contain these minerals. Available data for zincian spinel are even fewer than for garnet (von Knorring and Dearnley, 1959; Tulloch, 1981; Batchelor and Kinnaid, 1984; Spry and Scott, 1986a,b; Morris et al., 1997; Neiva and Champness, 1997; Szuszkiewicz and Lobos, 2004; Soares et al., 2007).

This project has a dual pronged approach that includes a detailed study of the major and trace element chemical composition of gahnite and garnet from Li-rich and -poor granitic pegmatites, as well as in LCT (lithium, cesium, and tantalum) and NYF (niobium, yttrium, and

fluorine; Černý and Ercit, 1995) and other kinds of pegmatites, to define chemical exploration guides for the search of this kind of ore. The hypothesis is that the major and trace element chemical composition of gahnite and garnet will be different in Li-rich and Li-poor pegmatites and this can be used as exploration guides to ore. To test this hypothesis, gahnite and garnet samples were obtained from different pegmatites around the world in geologic context and analyzed for major and trace element chemical compositions by electron microprobe (EMP) and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). In addition, an in-depth review of previously published compositions was conducted and used in the study in conjunction with the new data.

Results of this research will prove to be useful in the search for Li mineralization in the U.S. and elsewhere in the world, and will shed light on the model of formation of these economically and strategically important deposits. Through this research we have also enhanced technique development by developing a LA-ICP-MS technique to analyze trace element contents in gahnite. The results of this study may ultimately contribute to issues related to the economy, as well as environmental impact and public health by investigating mineral deposits that are important sources of elements that are used for development of new clean technologies. In particular, because Li is used to make Li-rechargeable batteries for hybrid or electric vehicles, the results have the potential to contribute to reduce green house emissions, which in turn will improve public health. Overall, the development of new technologies will benefit the economy, locally and nationally, by creating new jobs and potentially reduce the costs of commuting.

SAMPLING AND ANALYTICAL METHODS

This study focused on the mineralogy and the major and trace element chemical composition of garnet and gahnite from well-characterized granitic pegmatites, both Li-rich and Li-poor, as well as LCT, NYF, and muscovite type pegmatites (Černý and Ercit, 2005) and those of doubtful classification. More than 120 samples were obtained from colleagues in Brazil, Argentina, the U.S., China, and Czech Republic, from field locations in Maine and North Carolina, and from the museum collections at the Smithsonian Institution in Washington, D.C. in collaboration with Mike Wise, and the American Museum of Natural History in New York. Pegmatites investigated include (Tables 1 and 2): Emmons, Morefield, Rutherford, Mt. Mica, and Allen Mica mine (Virginia); Maine Feldspar Quarry, Pulsifer, Lord Hill, Greenlaw, and Keith (Poland and Stoneham, Maine); Ben Murphy Mica Mine (Maryland); Sullins-Wiseman, Hoot Owl, Bon Ami, Ray, Sinkhole, and Burleson Mica Mine, Spruce Pine district, Appalachians (North Carolina); Cryogenie, Elizabeth R, Oceanview, Pala Chief, and King Mine (San Diego and Pala Co., California); San Miguel (New Mexico); Batchellerville, Bayliss, Benson, and Greenfield (New York); Avondale (Pennsylvania); Alto Mirador, Boqueirão, Capoeira II, Carrascão, and Quintos, Borborema Pegmatite Province (BPP) (northeastern Brazil); Blanco Dora, Juan Román, La Magdalena, La Ona, Sin Nombre, and Nancy, Conlara and Comechingones districts, Pampean Pegmatite Province (Argentina); Elba (Italy); Guangdong (China); Szklary and Strzegom (Poland); Ontario (Canada); and Mocuba (Mozambique).

Polished-thin sections and polished-thick (~200 µm) sections were obtained from the same sample commercially (from Vancouver Petrographics) from 21 gahnite-bearing pegmatites and 28 garnet-bearing pegmatites. Polished thin sections were used to conduct petrographic analysis, scanning electron microscope (SEM) with energy dispersive spectroscopy (EDS), and electron microprobe (EMP) analysis, whereas polished thick sections were used for LA-ICP-MS analysis. Petrographic analysis was conducted at East Carolina University (ECU) using

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Olympus BX51 and BX41 dual reflected/transmitted light microscopes to determine the mineralogy, including the presence of rare metal mineral inclusions. Garnet and gahnite crystals were investigated and inclusion-free areas were selected for EMP and LA-ICP-MS analysis after imaging them under the petrographic microscope and SEM (Figs. 1 and 2). The SEM used is a FEI Quanta 200 Mark 1 microscope interfaced with an INCA energy dispersive spectroscopy system housed in the Biology Department at ECU. After LA-ICP-MS analysis, further SEM-EDS analysis was conducted to image the laser pits and better determine their context.

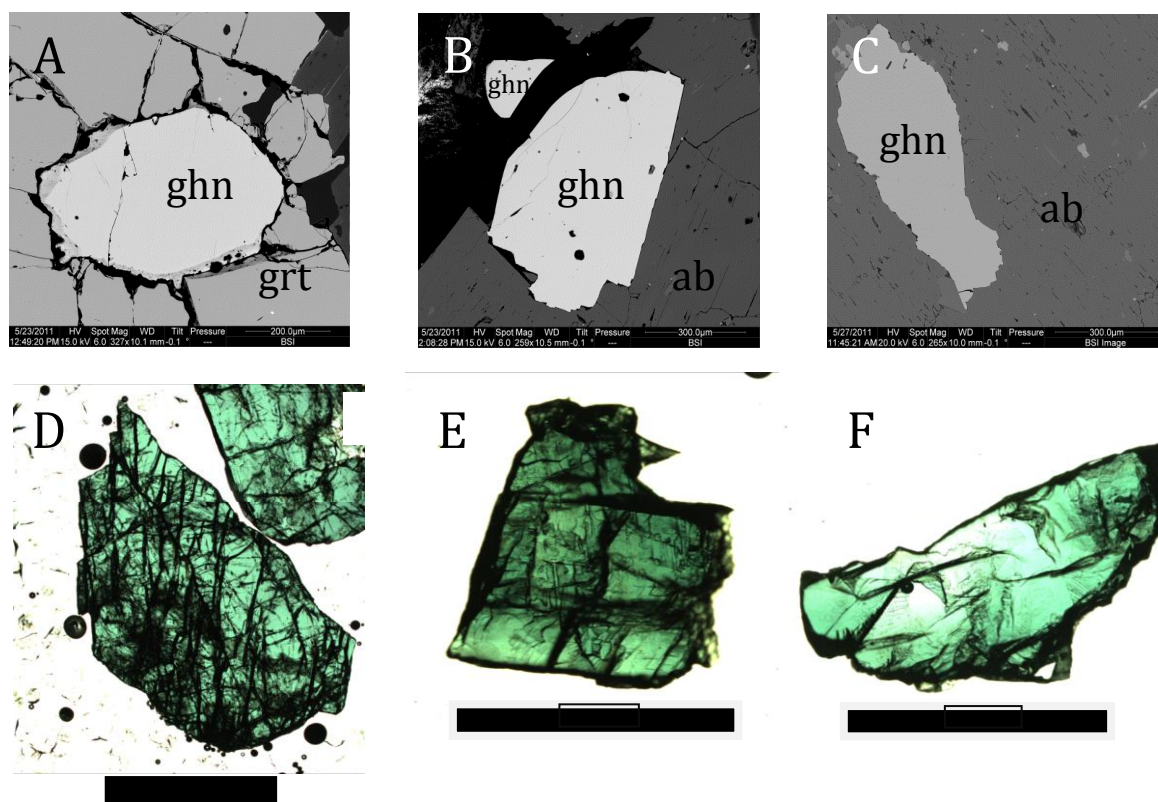


Figure 1. A. SEM image of gahnite (ghn) inclusion in garnet (grt), Boqueirão pegmatite, BPP, Brazil. B. SEM image of gahnite in albite (ab), Alto Mirador pegmatite, BPP, Brazil. C. SEM image of gahnite in albite, Capoeira 2 pegmatite, BPP, Brazil. D. Photomicrograph of gahnite, Juan Román pegmatite, Argentina. Scale bar = 5 mm. E and F. Gahnite crystals from Topsham, ME. Scale bar = 1 mm.

More than 1000 analyses of gahnite and more than 2000 analyses of garnet were obtained at the Smithsonian Institution, Washington, D.C., using a JEOL 8900 Superprobe electron microprobe and at Fayetteville State University (FSU) using a JEOL JXA 8530F Hyperprobe electron microprobe. Analyses included individual spots and transects across crystals. A multi-element suite of 52 elements (including Li, REE, Cs, Sn, Nb, Ta, Zn, Cu, Co, Ni, Cr, As, Sb, Ba, Se, and Cd among others) was analyzed in garnet (>1,000 analyses) and gahnite (900 analyses) by LA-ICP-MS with collaborator Dr. Alan Koenig in the fall of 2013. Major element contents were used as internal standards for LA-ICP-MS analysis. The LA-ICP-MS instrument used, housed in the USGS laboratory in Denver, is an ELAN DRC-e ICP-MS connected to an Analyte G2 Excimer Laser Ablation system. Individual spot analyses as well as transects across crystals

were performed to check for zonation. Analyses were carefully scrutinized and data derived from the presence of inclusions were filtered. Statistical analysis of data is currently being conducted to obtain correlations among different elements and elemental ratios in gahnite and garnet. The compositions and the results will be presented in scientific meetings and published in peer review journals within the next few months.

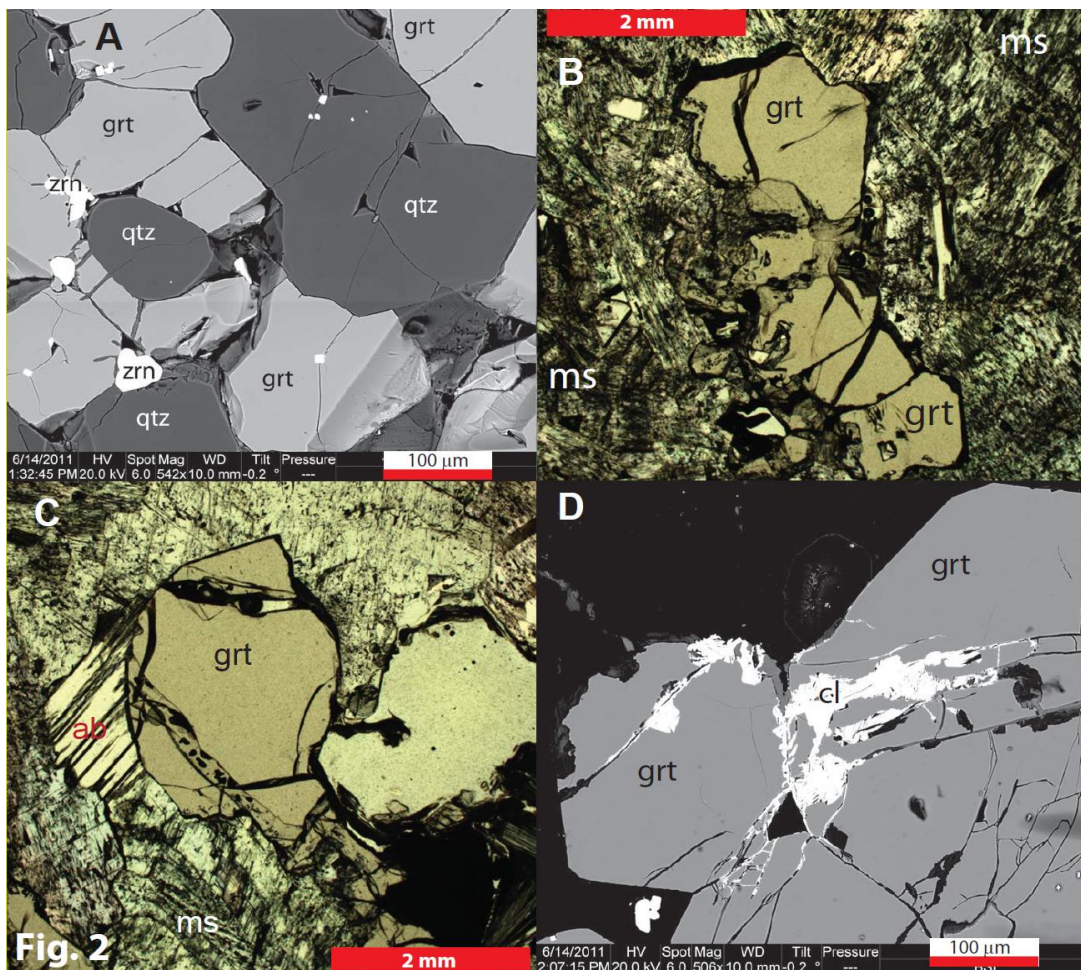


Figure 2. A. SEM image of garnet (grt) with quartz (qtz) (Capoeira 2, Brazil). B. Photomicrograph of garnet with muscovite (ms) (Alto Mirador, Brazil). C. Photomicrograph of garnet with albite (ab) and muscovite (Alto Mirador, Brazil). D. SEM image of garnet with fractures filled by columbite (cl) (Capoeira 2, Brazil).

RESULTS

A total of > 3,000 major element chemical compositions of garnet and gahnite in different kinds of pegmatites, including Li-rich and Li-poor pegmatites, and LCT, NYF, and muscovite type pegmatites (Černý and Ercit, 2005) as well as those of doubtful classification, were obtained in the present study. Results for garnet and gahnite are presented in Figs. 3 and 4, respectively. The chemical compositions of garnet and gahnite were also obtained from a small metamorphosed massive sulfide deposit in Australia to determine differences in the composition of the minerals in pegmatites and metamorphosed massive sulfide deposits. In addition to the new compositions obtained here, this study includes an in-depth compilation of major element

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chemical compositions of garnet and gahnite in pegmatites published in the literature, including those from Brazil (Alto Mirador, Boqueirão, Capoeira, Escondido, Poaia, Quintos), Canada (Cat Lake - Winnipeg River pegmatite field; Separation Rapids, Ontario), China (Mufushan and Keketuhai), Czech Republic (Hina), Finland (Kimito and Perniö), Great Britain (South Harris), Ireland (Aclare), Israel (Elat), Italy (Vinschgau Valley), Japan (Uzumine), Nigeria, Norway (Froland and Evje-Iveland), Poland (Strzegom-Sobótka), Portugal (Cabanias and Serra de Arga), Spain (Belvís), Switzerland (ZPU-Brissago), Thailand (Nong Sua), and the USA (Auburn, Topsham, and Lord Hill (Maine), George Ashley Block, Himalaya, and Little Three (California), Rutherford #2 (Virginia), Sebago, Siskoe Ridge (Spruce Pine, North Carolina) (e.g., Anderson et al., 1998; Batchelor and Kinnaird, 1984; Bogoch et al., 1997; Černý and Ercit, 2005; Eeckhout et al., 2002; Hoenig et al., 2010; Linnen and Williams-Jones, 1993; Morgan and London, 1999; Müller et al., 2012; Nakajima et al., 2006; Rose et al., 1997; Soares, 2004; Soares et al., 2007, 2008; Solva et al., 2003; Swanson and Veal, 2010; Vignola et al., 2008; Whitworth, 1992; Wise and Brown, 2009; Wise, 2007) (Figs. 3-6).

Garnet compositions

The composition of garnet from the Li-rich, LCT Quintos pegmatite (BPP) exhibits the highest degree of pegmatite evolution of all the pegmatites analyzed in this study, as seen in a plot of FeO+MgO versus CaO+MnO in wt.% (Fig. 1). Given in terms of spessartine (Spss) and almandine (Alm) end members (mol %), these garnets have a compositional range of $\text{Spss}_{90-94}\text{Alm}_{2-7}$. The least evolved of the pegmatites, based on the composition of garnet obtained in this study, is the Li-poor, NYF Batchellerville (NY) pegmatite, with a compositional range of $\text{Spss}_{2-3}\text{Alm}_{86.6-86.8}$. Garnet from the Li-rich, LCT Little Three Mine (CA) pegmatite (Morgan and London, 1999) has a wide range of compositions reflecting a low-to-high degree of melt evolution, with the most Mn-rich garnet having an extreme composition of $\text{Spss}_{98}\text{Alm}_2$. In contrast, the Li-poor, LCT Nong Sua (Thailand) pegmatite (Linnen and Williams-Jones, 1993) has the highest Fe content of the garnets analyzed in previous studies, and has a composition defined by $\text{Spss}_{<1}\text{Alm}_{37-63}$.

This study shows that even though the compositional ranges of garnet within some individual pegmatites can be quite large and are useful indicators of pegmatite melt evolution, garnet in many individual pegmatites have restricted compositional ranges. Considering all the garnet compositions available, Li-poor, NYF pegmatites typically have garnet with the lowest Mn and highest Fe contents, whereas garnet in Li-rich, LCT pegmatites has the highest Mn and lowest Fe contents. This suggests that the major element composition of garnet can be used to distinguish pegmatites with Li mineralization from those with low Li contents. Trace element chemical compositions of garnet (>1,000) are currently being used to produce discriminator diagrams for Li-rich vs. Li-poor pegmatites and those from metamorphosed massive sulfide deposits. Trace element compositions of garnet will likely be good indicators of Li mineralization in granitic pegmatites.

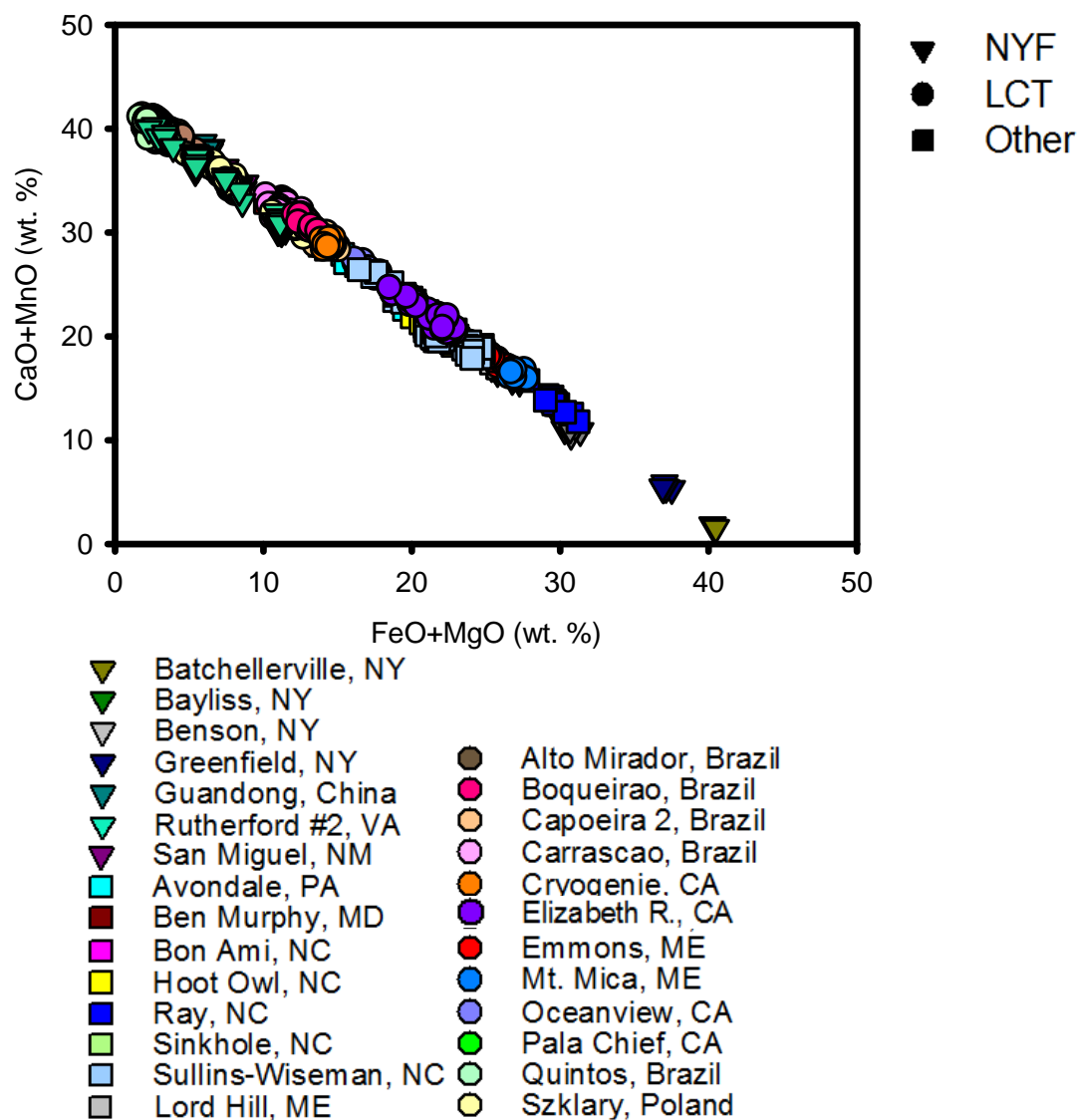


Figure 3. Binary diagram in terms of FeO+MgO vs. CaO+MnO (in wt. %) showing the composition of garnet in granitic pegmatites obtained in this study grouped into LCT and NYF (Černý, 1991), and those of doubtful classification. After Baldwin and von Knorring (1983). Circles represent LCT pegmatites, triangles NYF pegmatites, squares muscovite pegmatites, mixed type, and uncertain type pegmatites. Analysis by electron microprobe. Modified from Moretz et al. (2013).

Gahnite compositions

Gahnite compositions from the study sites, expressed in terms of hercynite (Hc), gahnite (Ghn), and spinel (Spl) end members (mol %), fall within the igneous pegmatite field (Batchelor and Kinnaird, 1984; Spry and Scott, 1986b; Heimann et al., 2005). The range of these compositions can be defined by: $Hc_{0.0-27.0}Ghn_{72.1-98.5}Spl_{0.0-4.7}$. Gahnite compositions in the Strzegom-Sobótka (Poland) NYF pegmatite provide evidence for the lowest degree of evolution

of all the LCT and NYF pegmatites studied, whereas those from the BPP LCT pegmatites indicate the highest degree of evolution among all the pegmatites.

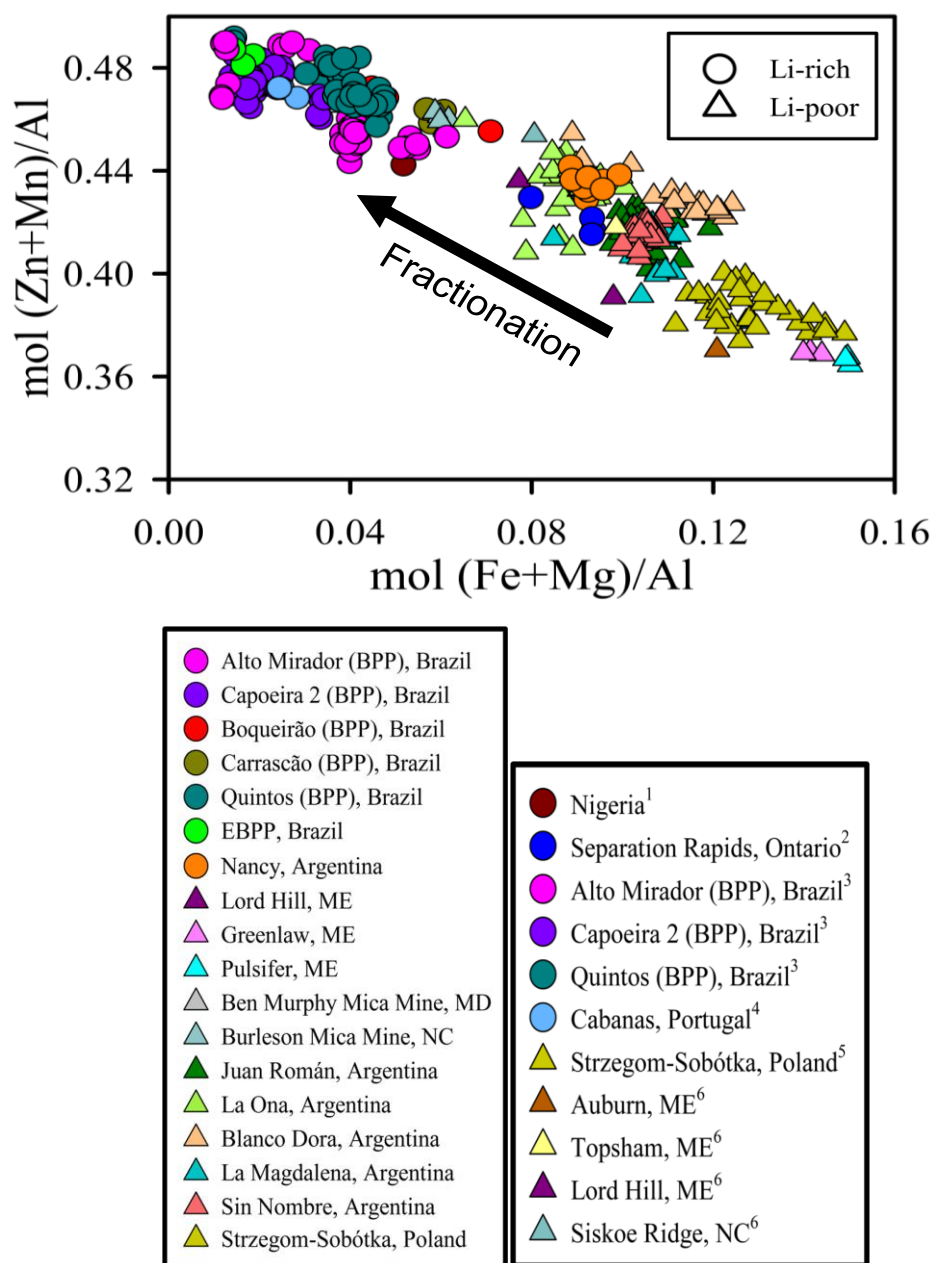


Figure 4. Binary diagram in terms of mol (Fe+Mg)/Al vs. mol (Zn+Mn)/Al showing the composition of gahnite obtained in this study and from previous studies. After Batchelor and Kinnaird (1984). Circles represent Li-rich pegmatites and triangles Li-poor pegmatites. Analysis by electron microprobe. Unpublished results, Jason Yonts MS thesis, in progress.

The compositions of gahnite from Argentina pegmatites reflect moderate evolution and plot between the Poland and Brazil pegmatites. Based on the composition of gahnite, some Argentina pegmatites (i.e., La Magdalena, Juan Román) are the least evolved of the studied LCT pegmatites. They include Li-rich and Li-poor pegmatites, and the Li-rich have higher Zn content than the Li-poor pegmatites. Gahnite in the La Ona pegmatite from Argentina displays the highest degree of evolution among the Argentina pegmatites. Gahnite from the NYF-type Strzegom-Sobótka pegmatite has the highest Fe and lowest Zn content of all the studied LCT and NYF pegmatites, and its composition is described as $Hc_{18.9-25.5}Ghn_{74.0-81.5}Spl_{0.1-0.6}$. On the other hand, gahnite from the LCT pegmatites has the highest Zn content ($Hc_{0.0-20.2}Ghn_{78.8-98.5}Spl_{0.0-4.7}$) of all pegmatites, with those from Carrascão and Capoeira 2 (BPP) reflecting the highest degree of evolution.

The highest Zn content in gahnite is characteristic of more fractionated magmas (Batchelor and Kinnaid, 1984) and is associated with LCT-type and Li-rich pegmatites. A plot of mol (Fe+Mg)/Al vs. mol (Zn+Mn)/Al additionally proves that gahnite from NYF-type pegmatites exhibits the lowest degree of fractionation, while gahnite from the LCT-type pegmatites shows the highest degree of fractionation (Figs. 4-6). The data obtained in this study and those derived from limited previous studies indicate that Li-rich pegmatites have gahnite with elevated Zn content ($Ghn > 90$ mol. %), whereas Li-poor pegmatites have gahnite with comparatively lower Zn content (Fig. 6). However, some overlap exists between the two types of pegmatites and this needs further investigation. Our results show that gahnite compositions can be used to differentiate Li-rich from Li-poor pegmatites, and that even though gahnite is not abundant in NYF pegmatites, its composition can also serve to distinguish NYF from LCT pegmatite sources. Trace element data for gahnite are currently being analyzed statistically to produce discriminator diagrams for Li-rich vs. Li-poor pegmatites and those from metamorphosed massive sulfide deposits. Trace element compositions of gahnite will likely be good indicators of Li mineralization in granitic pegmatites.

CONCLUSIONS

This study shows that even though the compositional ranges of garnet within some individual pegmatites can be quite large and are useful indicators of pegmatite melt evolution, garnet in many individual pegmatites have restricted compositional ranges. Considering all the garnet compositions available, Li-poor, NYF pegmatites typically have garnet with the lowest Mn and highest Fe contents, whereas garnet in Li-rich, LCT pegmatites has the highest Mn and lowest Fe contents. This suggests that the major element composition of garnet can likely be used to distinguish pegmatites with Li mineralization from those with low Li contents. The ongoing study of trace element compositions in pegmatitic garnet will likely prove them to be good indicators of Li mineralization in granitic pegmatites.

The highest Zn content in gahnite is characteristic of more fractionated magmas (Batchelor and Kinnaid, 1984) and is associated with LCT-type and Li-rich pegmatites. A plot of mol (Fe+Mg)/Al vs. mol (Zn+Mn)/Al additionally proves that gahnite from NYF-type pegmatites exhibits the lowest degree of fractionation, while gahnite from the LCT-type pegmatites shows the highest degree of fractionation. The data obtained in this study and those derived from limited previous studies indicate that Li-rich pegmatites have gahnite with elevated Zn content, whereas Li-poor pegmatites have gahnite with comparatively lower Zn content. Our results show that gahnite compositions can be used to differentiate Li-rich from Li-poor

pegmatites, and that even though gahnite is not abundant in NYF pegmatites, its composition can also serve to distinguish NYF from LCT pegmatite sources.

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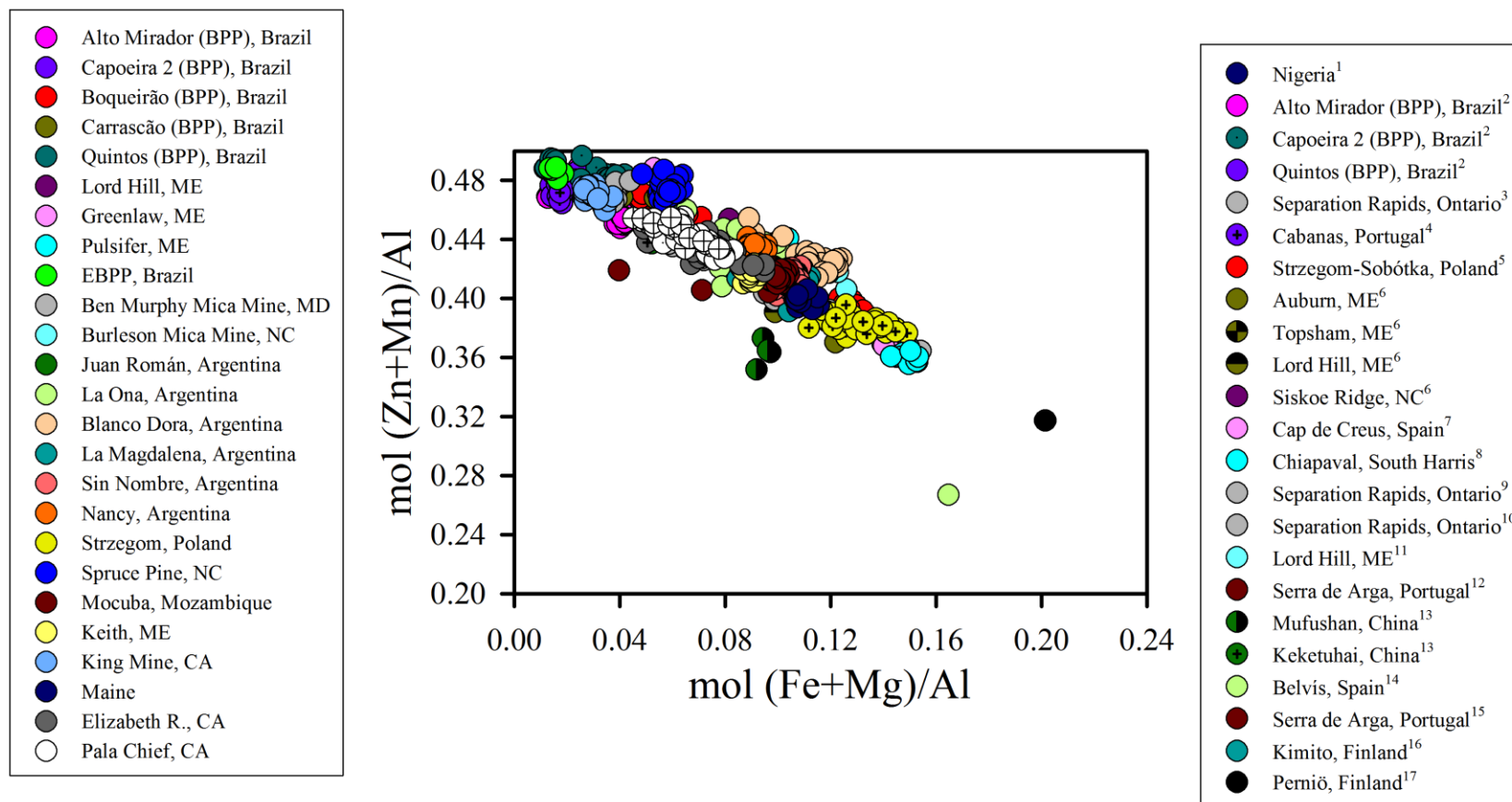


Figure 5. Binary plot in terms of mol (Fe+Mg)/Al vs. mol (Zn+Mn)/Al showing the compositions of gahnite in granitic pegmatites analyzed in this study and previous studies. Analysis by electron microprobe. References for literature data are: 1 Batchelor and Kinnaird (1984); 2 Soares et al. (2007); 3 Morris et al. (1997); 4 Neiva and Champness (1997); 5 Szuszkiewicz and Lobos (1994); 6 Spry and Scott (1986b); 7 Alfonso (1995); 8 von Knorring and Dearnley (1960); 3, 9 and 10 Dunlop (2000); 11 Johnson (1998); 12 Tindle and Breaks (1998), Li et al. (1999); 14 Merino et al. (2013); 15 Leal Gomes et al. (1995); Dias (2011); 16 Pehrman (1948); 17 Eskola (1914). Unpublished data, Jason Yonts MS thesis, in progress.

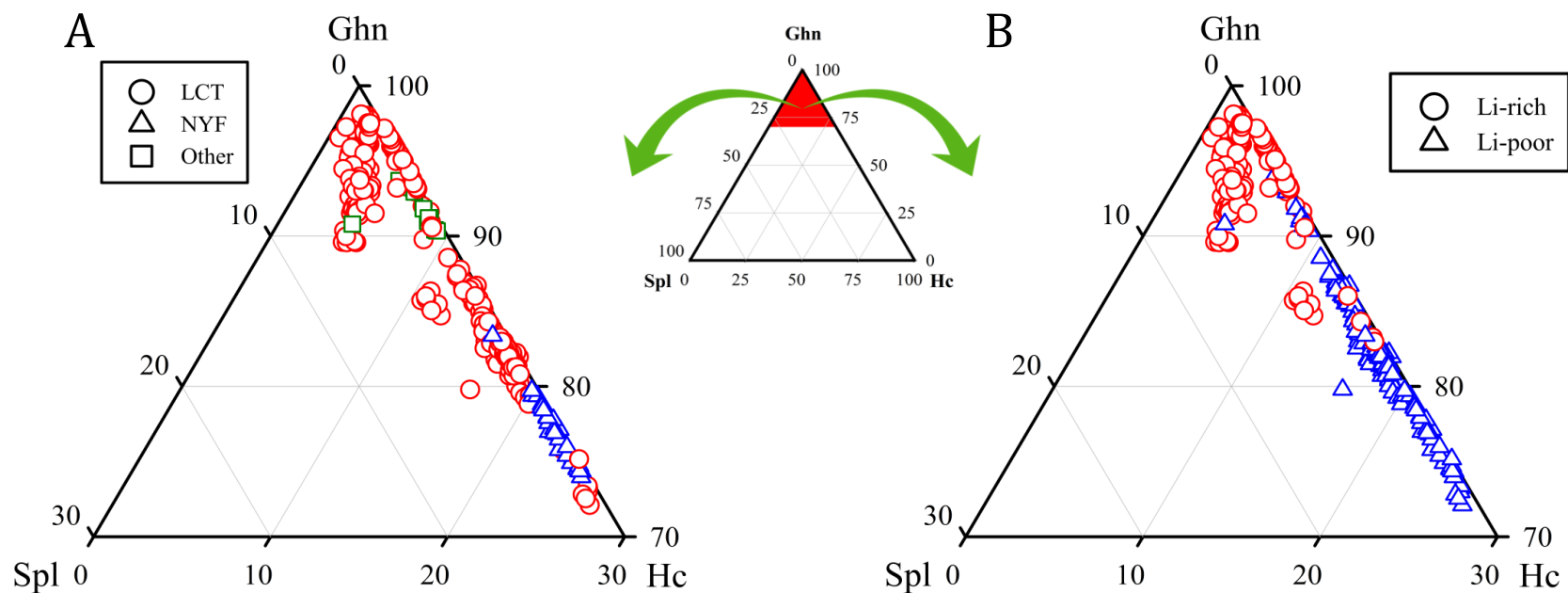


Figure 6. Summary ternary diagrams showing the composition of zincian spinel in all granitic pegmatites in terms of the Ghn, Hc, and Spl end members. **A.** Circles represent LCT pegmatites, triangles NYF pegmatites, and squares other pegmatites. **B.** Circles represent Li-rich pegmatites and triangles represent Li-poor pegmatites. Analysis by electron microprobe. Unpublished results, Jason Yonts MS thesis, in progress.

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Table 1. Summary of the main characteristics of pegmatites that contain gahnite analyzed in this study

Name	Type	Location	Li-Rich / Li-Poor	Rare Metal Mineralization	Host Rocks	Age	References
Alto Mirador	Rare-element granitic pegmatite (LCT)	Borborema Pegmatite Province (BPP), Brazil	Li-rich	Ta, Be, Li (in lepidolite)	Quartzite	Neoproterozoic	Soares et al. (2008)
Capoeira 2	REE-spodumene subtype (LCT)	BPP, Brazil	Li-rich	Be, Li, Ta, Nb, Ti, U	Quartzite and metaconglomerates of the Equador Formation	Neoproterozoic	Soares et al. (2008), Beurlen et al. (2008, 2009a; 2011)
Boqueirão	Rare-element granitic pegmatite (LCT)	BPP, Brazil	Li-rich	Li, Ta, Nb, Be, U, Bi	Metaconglomerates of the Equador Formation	Neoproterozoic	Soares et al. (2008), Beurlen et al. (2009a)
Carrascão	REE-lepidolite subtype (LCT)	BPP, Brazil	Li-rich	Be, Li, Ta, Nb, Ti, U	Quartzite and metaconglomerates of the Equador Formation	Neoproterozoic	Beurlen et al. (2008; 2009a)
Quintos	REE-spodumene subtype (LCT)	BPP, Brazil	Li-rich	Li, Ta, Nb, Ti, U, Be	Quartzite and metaconglomerates of the Equador Formation	Neoproterozoic	Soares et al. (2008), Beurlen et al. (2008; 2009b)
Lord Hill	LCT/NYF - Rare element (beryl-columbite-phosphate)	Paris-Rumford District; Stoneham, Maine	Li-poor	Nb, Ta	Diorite	325 Ma	Johnson (1998); Woodard (1951)
Greenlaw	LCT - Rare-element (beryl-columbite)	Oxford Pegmatite Field; Auburn, Maine	Li-rich	Nb, Ta, Be	Metasedimentary rocks	-	Wise, M. (pers. comm.)
Pulsifer	LCT - Rare-element (beryl-columbite-phosphate)	Oxford Pegmatite Field; Auburn, Maine	Li-rich	Nb, Ta, Be	Pegmatitic granite	-	Wise, M. (pers. comm.)
	LCT - Rare-element?	Eastern Brazil Pegmatite Province	Li-rich?	Li, Be, Ta, Cs	-	525-545 Ma	Morteani et al. (2000)
Ben Murphy Mica Mine	Muscovite-rare element	Maryland	Li-poor	U, Nb, Ta, Be	-	Late Cambrian	Bernstein (1976)
Burleson Mica Mine	Muscovite-rare element	Spruce Pine District; Siskoe Ridge (near Spruce Pine), North Carolina	Li-poor	REEs	Amphibolite	377 Ma	Spry and Scott (1986b)

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Juan Román	REE - beryl-columbite-phosphate subtype (LCT)	Comechingones, Argentina	Li-poor	Be, Nb	Augen-gneiss	466-530 Ma	Hub (1994); Galliski and Sfragulla (2014)
La Ona	REE - beryl-columbite-phosphate subtype (LCT)	Comechingones, Argentina	Li-poor	Be, Nb	Augen-gneiss	466-530 Ma	Hub (1994); Galliski and Sfragulla (2014)
Blanca Dora	REE - beryl-columbite-phosphate subtype (LCT)	Comechingones, Argentina	Li-poor	Be, Nb	Cordieritic diatexites	466-530 Ma	Galliski (1999); Galliski and Sfragulla (2014)
La Magdalena	REE - beryl-columbite-phosphate subtype (LCT)	Comechingones, Argentina	Li-poor	Be	Augen-gneiss	466-530 Ma	Hub (1994); Galliski and Černý (2006); Galliski and Sfragulla (2014)
Sin Nombre	REE - beryl-columbite-phosphate subtype (LCT)	Comechingones, Argentina	Li-poor	Be	Augen-gneiss	466-530 Ma	Rinaldi (1968); Galliski and Sfragulla (2014)
Nancy	REE - beryl-columbite-phosphate subtype (LCT)	Conlara pegmatite field, Argentina	Li-rich?	Be, P, Nb	Medium-grade gray gneiss	435-500 Ma	Tait et al. (2004); Galliski and Sfragulla (2014)
Strzegom-Sobótka	NYF	Strzegom-Sobótka massif; Siedlimowice, Poland	Li-poor	Nb, Ta	Two-mica granite	287-311 Ma	Szuskiwicz and Lobos (2004)
Mocuba		Alto Ligonha District, Mozambique	-				n/a
Pala Chief	LCT	California	Li-rich				n/a
Elizabeth R.	LCT	California	Li-rich				n/a

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Table 2. Summary of the main characteristics of pegmatites that contain garnet analyzed in this study

Pegmatite	Type	Location	Li-Rich / Li-poor	Rare metal mineralization	Enclosing Rocks	Age	Ref.
Alto Mirador	Rare-element granitic pegmatite (LCT)	Borborema Pegmatite Province, (BPP) Brazil	Rich	Ta, Be, Li (in lepidolite)	Quartzite	Neoproterozoic	Soares et al. (2008)
Capoeira 2	Rare-element granitic pegmatite (LCT)	BPP, Brazil	Rich	U, Li, Ti, Ta, Nb	Quartzite and metaconglomerates of the Equador Formation	Neoproterozoic	Soares et al. (2008)
Boqueirao	Rare-element granitic pegmatite (LCT)	BPP, Brazil	Rich	Li, Ta, Be, U, Bi	Metaconglomerates of the Equador Formation	Neoproterozoic	Soares et al. (2008)
Carrascao	Rare-element granitic pegmatite (LCT)	BPP, Brazil	Poor?		Quartzite and metaconglomerates of the Equador Formation	Neoproterozoic	
Quintos	Rare-element granitic pegmatite (LCT)	BPP, Brazil	Rich	Li, Ta, Nb, Ti, U	Quartzites of the Equador Formation	Neoproterozoic	Soares et al. (2008)
Rutherford #2	NYF	Amelia, VA	Poor	Nb, Ta, Y, Ce, Ca, La	Late Pre-Cambrian to early Paleozoic gneisses	279 Ma	Arredondo et al. (2001), Lumpkin (1998)
Szklary	Literature suggests it may be Rare-Element Granitic (LCT)	Lower Silesia, southeastern Poland	Poor	Ce, Y, U, Dy, Hf, Ta, Nb, Sb, As	Early Carboniferous gneiss (part of a tectonically active ophiolite suite)		Pieczka (2007)
Bayliss Quarry	NYF	Bedford, New York	Poor				n/a
Greenfield	NYF and also abyssal to muscovite	Saratoga Co., New York	Poor	Ce, Y	Proterozoic metasedimentary rocks		Lupulescu et al. (2011)
Benson Mines	NYF	St. Lawrence Co., New York	Poor				Palmer (1970)
Batchellerville	NYF and also abyssal to muscovite	Saratoga Co., New York	Poor	Ce, Y	Proterozoic metasedimentary rocks		Lupulescu et al. (2011)
Fonte de Prete	Rare-element class (LCT)	Elba, Italy	Poor	Ti, Nb, Ta, Y, Ca, Ce, Th, U	Peraluminous monzogranite	6.7-6.9 Ma	Aurisicchio et al. (2002)
Lord Hill	Rare-element class (LCT)	Stone Ham, ME	Poor	Nb, Ta	Diorite	325 Ma	Rochester Mineralogical Symposium (1996)
Elizabeth R. Mine, King Mine	Rare-element (Complex) (LCT)	Pala Dist., San Diego Co., California	Rich				n/a
Ben Murphy Mica Mine	Muscovite-rare element	Maryland	Poor	U, Nb, Ta, Be	-	Late Cambrian	Bernstein (1976)

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Siskoe Ridge	Muscovite-rare element	Siskoe Ridge (near Spruce Pine, NC)	Poor	REEs	Amphibolite	377 Ma	Spry and Scott (1986b)
	Muscovite-rare element	Avondale, PA	Poor				n/a
	NYF	San Miguel Co., NM	Poor				n/a
	NYF	Yunnan, China; Guangdong, China	Poor				
Emmons	Rare-element (Complex-petalite (LCT))	Maine	Rich	Li (spodumene)	Granite; qtz-bt-ms schist		Sundelius (1963)
Mt. Mica	Rare-element (Complex-petalite) (LCT)	Maine	Rich		Schist; aplitic granite		Dyar et al. (1999)
Oceanview	Rare-element (Complex-spodumene) (LCT)	Pala Dist., San Diego Co., California	Rich?				n/a
Cryogenie	LCT - Rare-element (Complex-lepidolite)	Pala Dist., San Diego Co., California	Rich				n/a
Strzegom-Sobotka	NYF	Siedlimowice, Poland	Poor	Nb, Ta	Two-mica granite		Szuskiwicz and Lobos (2004)

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